Can silvicultural treatments improve the water economy?

by Jerome K. VANCLAY

Four facts about water and forests are well-known and commonly accepted, but conflict with the commonly held view that trees use water to the detriment of water catchments (e.g., DIJK and KEENAN 2007):

– trees can transpire relatively large amounts of water, which is often considered "lost" (FARLEY *et al*. 2005, JACKSON *et al*. 2005);

– cloud condensation nuclei produced by forest canopies (O'DOWD *et al*. 2002, SPRACKLEN *et al*. 2008) mean that forests may be important in clouds formation;

– the atmosphere holds relatively little moisture (DUAN *et al*. 1996, TREGONING *et al*. 1998), setting a limit to the amount of transpired water than can be retained in the atmosphere;

– and most water vapour in the atmosphere does not travel far before it falls back to earth (BOSILOVICH and CHERN 2006, FITZMAURICE 2007).

The apparent contradictions amongst these four points pose the question: what is the fate all the water "lost" from trees if it is not retained in the atmosphere, doesn't travel far, and is likely to be condensed over forest? Is evapotranspiration "lost" or does it fall nearby as rain? These are important questions, but are infrequently addressed because relatively few researchers take a broad systems view that includes the atmosphere, and a narrower focus on individual trees can lead to a different (and potentially misleading) conclusion.

One such view that may be over-simplistic is the assumption that plantation water use is age-related. Several meta-analyses have illustrated a trend between water use and age (e.g., FARLEY 2005, JACKSON *et al.* 2005), and while such a correlation certainly exists, it is not necessarily causal and may merely be a proxy for other factors such as leaf area, tree height or canopy roughness (VANCLAY 2009). Some may argue that this subtlety doesn't matter, because the correlation with age may be useful for prediction, but the distinction is of practical importance, because forest managers can change the later (e.g., leaf area, canopy roughness) more readily than plantation age which may be constrained by the forest products that are to be produced.

The similarity between water use and age-based tree growth patterns convinces many people that the relation is causal and is related to water use in wood formation, but the water directly involved in photosynthesis is minor and most of the water used by trees is used to transport nutrients and cool the tree. Closer observation of plantation development suggests a better explanation may be offered by canopy structure (roughness) and water use.

The Penman-Monteith equation offers an alternative theoretical approach to examine water use (IRMAK *et al.* 2005), using an energy balance approach rather than an empirical correlation. The Penman-Monteith equation reveals that much of the water used is transpired on days with low humidity and high wind; and that potential water use is well-correlated with relative humidity, windspeed and canopy roughness (or aerodynamic resistance). Foresters cannot readily manage humidity, but can influence wind speed and canopy roughness. Agriculture and horticulture have relied for decades on management of wind with windbreaks (e.g., CLEUGH 1998), and the same principles can be applied principles to create water-wise plantations.

One clue that water use may be reduced by internal windbreaks comes from water use patterns in natural eucalypt forests in which canopy structure varies greatly between irregular old-growth (with "windbreak" trees) and even-aged regrowth (without windbreaks; e.g., VERTESSY *et al.* 1998). Thus it seems possible that internal "windbreaks" within a plantation could create a water-wise forest more like old-growth forest. The number and layout of windbreaking trees required within a plantation to quench thirsty regrowth remains an interesting research question. Careful species selection may be needed to ensure water savings are achieved with internal windbreaks, and ensure that these do not merely simply swap one problem for another. Species differ greatly in their ability to control stomata, with some species maintaining a very frugal water balance, while others remain at the mercy of the elements (JONES 1998, WHITEHEAD and BEADLE 2004).

There is evidence that mixed-species stands offer hydrological as well as other benefits. FORRESTER (2007, 2010) reported greater production efficiency (ratio of transpiration:assimilation) in mixed species plantings compared with pure stands. Pure *Acacia mearnsii* achieved 1406 (± 302) Ml/m^3, but improved to 882 (± 98) Ml/m^3 when mixed with *Eucalyptus globulus*. It seems likely that the different statures exhibited by these two species helped to create this effect, as the eucalypt tends to be tall and narrow, whereas the acacia tends to be shorter and broader, offering a mutual benefit: the taller eucalypts provide shelter for the acacia, and the leguminous acacias provide nitrogen for the eucalypts.

Another way to modify water use through the structure of the canopy is through the boundary layer that influences how the air near the trees mixes with the upper atmosphere. Even-aged plantations have a very different boundary layer than mixed-species plantations and old-growth forests, and this is reflected in their water use. Canopy texture is important, because it affects the aerodynamics, especially the turbulence and the boundary layer. Fortunately, it is relatively easy for forest managers to manipulate canopy texture through species selection and thinning regimes. However, many plantations are relatively small, and edge effects are important (WUYTS *et al.* 2009). It is clear that unproductive transpiration can be reduced by softening plantation edges through pruning and thinning, by avoiding unnecessary breaks in the canopy, and possibly with hedges to create more aerodynamic edges (VANCLAY 2009).

Readers should not develop the impression that it is too difficult and impractical to miti-

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gate water loss from plantations through silviculture. Although there remains a great need for research in this area (VANCLAY 2009), practical solutions do exist, and "best bets" can be implemented immediately. These solutions are not universal, and thoughtful approaches are needed to adapt species, sites and silviculture to the hydrological outcomes desired in each specific case.

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